Cover Crops In Apple Orchards On Arsenic-toxic Soils

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Cover Crops in Apple Orchards on Arsenic-toxic Soils

By F. L. Overley*

The principal objectives of the work reported in this bulletin were: (*a*) to find the cause of decline in the growth of alfalfa cover crops, and (*b*) to find means of establishing and maintaining satisfactory cover crops.

Cover Crops Have Become Increasingly Harder to Establish in Central Washington Orchards

TILLAGE

During the period of about 1900 to 1915, clean tillage was a general soil management practice for commercial apple production in the irrigated valleys of central Washington. The frequent deep cultivations needed to maintain a dust mulch and to destroy weed growth often resulted in the destruction of mulch of the tree root growth in the upper 5 or 6 inches of soil. Irrigation water was applied in shallow ditches or rills spaced about 30 inches apart. These were newly made for each irrigation, since they were obliterated by cultivation between irrigations. Considerable erosion resulted, especially in orchards on the steeper slopes.

The orchards planted on virgin soils thrived for the first 10 or 15 years, but the intensive cultivation program caused rapid depletion of soil organic matter and available nitrogen, with a consequent tendency toward lower fruit yields, declining tree vigor, and the development of rosette, or little leaf. Cover crops, usually alfalfa, were then started in many orchards with beneficial results. About 1920, the cover system of soil management with alfalfa as permanent cover crop was generally practiced by apple growers in the irrigated areas of central and north central Washington.

IRRIGATION

The irrigation methods used for clean tillage were satisfactory for starting new cover crops. Later, as partially decomposed crop residue accumulated on the surface of the soil, it became difficult to carry the water through long, shallow, closely spaced irrigation furrows and to irrigate the orchard area within the allotted period of time with the amounts of irrigation water that were usually available. Hence, many fruit growers began spacing their irrigation furrows much farther apart. Five or six feet between relatively deep irrigation furrows was not uncommon. Thorough disking of the cover crop after harvest became a general practice.

COVER CROPS

Although alfalfa and, less extensively, sweetclover and other cover crops were grown successfully at first, it became increasingly difficult and finally almost impossible to re-establish le-

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The late Professor O. M. Morris of the Horticulture Department of The State College of Washington was in charge of the cover crop project when the work reported in this bulletin was conducted.

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guminous cover crops in many mature apple orchards in the Yakima and Wenatchee districts.

The result was that alfalfa and other leguminous cover crops gradually disappeared from mature apple orchards of these two districts during the period 1925 to 1940. The fruit trees began to show reduced vegetative growth and fruit production. A rosette (little leaf) condition of the trees again developed (12)[1] and became an increasingly serious problem. The soils became harder and packed more easily. Soil erosion became an important problem, especially with hillside orchards.

POSSIBLE CAUSES

The presence of arsenical compounds in the soil was found to be detrimental to crop growth (4, 10). However, annual application of large amounts of lead arsenate for codling moth control was required for the apple orchards of the Yakima and Wenatchee districts from the early plantings until 1946.

As a result of this past history, several causes were thought to contribute to the decline of alfalfa and to the difficulty of re-establishing it as a cover crop under the conditions existing in mature apple orchards: (*a*) Wide spacing of deep irrigation furrows and the annual deep disking killed the existing plants. (*b*) Apple trees became older and larger, which interfered with the preparation of the soil for re-seeding. (*c*) Dense shade retarded the growth of alfalfa and favored the growth of competing weeds and grasses. (*d*) Heavy continuous sprays of lead arsenate required for codling moth control had resulted in arsenic toxicity in the soil.

Lead Arsenate Spray Residues Poison Alfalfa

During 1930 and 1931, attempts were made to establish leguminous cover crops in the fertilizer plots of a mature apple orchard in the Wenatchee area. Common alfalfa, Ladak alfalfa, Hubam, and white biennial sweetclover were planted in a well-prepared seed bed in separate plots. The water applied by rill or sprinkler irrigation was ample at all times. The seed germinated, and the seedlings generally grew to a height of 2 inches. The growth stopped at this point, and by midsummer it was almost impossible to find any young plants under any of the mature apple trees. A somewhat satisfactory stand and growth resulted in areas where the trees were missing, or in areas well away from the perimeter of the large apple trees.

FIRST EXPERIMENT

Several experiments were conducted in 1935. In the spring of that year, an attempt was made to re-establish leguminous cover crops on plots in a block of mature Jonathan apple trees on Cashmere gravelly sandy loam at the Tree Fruit Experiment Station. Each plot represented a tree-row middle of six trees, or an area of 28 by 240 feet.

The seed bed was well prepared. Ammonium sulfate, 16 per cent superphosphate, and muriate of potash were applied to various plots in the following formulas: 5-8-0, 0-8-0, 5-0-0, 5-8-12, and no fertilizer. The rates for nitrogen were equivalent to 1 pound of N per tree. For phosphorus and potassium, the rates were in the proportions indicated in the formulas. Alfalfa, Hubam, and sweetclover were seeded in separate parts of each plot with a drill-type grass seeder. Irrigation rills 16 inches apart and about 4 inches deep were made immediately after seeding. Ample irrigation water was applied regularly.

The cover crop seeds germinated, but the growth of the seedlings stopped

[1] Numbers within parentheses refer to "Literature Cited," page 14.

when they had reached a height of 2 to 3 inches. After a short period of time, the underground part of the stems and the roots of the plants became brown. Later they became black. This was followed by the death of the plants.

SECOND EXPERIMENT

In a second experiment, representative soil samples taken to a depth of 6 inches were obtained from the fertilizer plots in a mature apple orchard on Ephrata fine sandy loam in East Wenatchee (13). Unsuccessful attempts had been made previously to re-establish alfalfa on the various fertilizer plots which had received annual applications, since 1927, at rates per tree of 5 pounds of ammonium sulfate, 6 pounds of superphosphate, and 5 pounds of muriate of potash, alone and in combinations.

The soil samples from each plot were mixed thoroughly and placed in a bottomless apple box set in direct sunlight in an excavation deep enough so that the top of the box was level with the soil surface. One hundred alfalfa seeds were planted in each box. No additional fertilizers were applied. The soil was kept moist by sprinkler irrigation. Alfalfa on soils which had received superphosphate for 8 consecutive years made a slightly better growth than on the other soils, but in no case was growth satisfactory.

THIRD EXPERIMENT

In the third experiment, soil samples were taken from a virgin area, from a nearby apple orchard where heavy sprays of lead arsenate had been applied for many years, and from a garden where no sprays had ever been applied. One part of the garden soil received no treatment. The other part received an amount of lead arsenate equivalent to that which would have accumulated from seven sprays for codling moth control. Ten lima bean seeds were planted in each soil. Lima beans were selected because they are sensitive to arsenic in the soil (17). The results indicated that although the beans germinated in all the soils, they failed to grow in the treated garden soil and in the orchard soil. They did make normal growth in the virgin and non-treated garden soils.

CONCLUSIONS

Observations made in the fertilizer plots in mature apple orchards at Manson, Peshastin, and Wenatchee confirm the results of the foregoing experiments in regard to poor stands and vigor of alfalfa. The results obtained by Vandecaveye, *et al.* (14, 15), on soil samples taken from apple orchards with mature trees, were similar. This suggested that the poor stands of alfalfa in apple orchards resulted primarily from a toxic condition of the soil contributed by arsenical spray residues, and perhaps also from the destruction of established alfalfa plants by excessive annual disking. There was no evidence that lack of plant nutrients, age and size of trees, or dense shade were important contributing factors.

In Sprays, the Arsenic—Not the Lead or Fluorine—Poisons Alfalfa

During the period when arsenical sprays constituted the chief insecticide for codling moth control, apple growers applied an average of six or more cover sprays per season in heavily infested orchards. Much of this fell to the ground and accumulated in the surface soil, since the products used are highly insoluble. Ten years of spraying often resulted in the accumulation of approximately 4,500 pounds of lead arsenate per acre in the surface 6 inches of soil. This is equivalent to about 3,222 pounds of lead and 900

pounds of arsenious trioxide (As_2O_3).[2]

LEAD

Since arsenical sprays contain lead as well as arsenic, it was of interest to know the effect of lead on plant growth. This was determined in a greenhouse experiment. Palouse silt loam was obtained from the College farm at Pullman, and various amounts of different lead and arsenate compounds were mixed with different lots of this soil. The treated soils were placed in 1-gallon tin cans in the greenhouse and planted with alfalfa on November 15. The condition of the alfalfa plants in regard to stand and growth, as observed 6 months later, is recorded in Table 1.

TABLE 1.—RESPONSE OF ALFALFA PLANTED IN PALOUSE SOIL UNTREATED AND TREATED WITH VARYING AMOUNTS OF LEAD ARSENATE, LEAD ACETATE, AND LEAD NITRATE.

Material applied	Rate per acre	Per cent stand	Condition of growth	Final outcome
			2% very weak & yellow	
Lead arsenate	1 ton	5	98% dead	Failure
Lead arsenate	2 tons	0	Dead	Failure
Lead arsenate	3 tons	0	Dead	Failure
Lead arsenate	4 tons	0	Dead	Failure
Lead arsenate	5 tons	4	1% very poor 99% dead	Good
Lead acetate	1 ton*	100	100% growth of plants	Good
Lead acetate	2 tons*	90	100% growth of plants	Good
Lead acetate	3 tons*	90	100% growth of plants	Good
Lead acetate	4 tons*	70	100% growth of plants	Good
Lead acetate	5 tons*	70	100% growth of plants	Good
Lead nitrate	1 ton*	100	100% growth of plants	Good
Lead nitrate	2 tons*	100	100% growth of plants	Good
Lead nitrate	3 tons*	100	100% growth of plants	Good
Lead nitrate	4 tons*	100	100% growth of plants	Good
Lead nitrate	5 tons*	100	100% growth of plants	Good
Check no treatment		100	100% growth of plants	Good
Check no treatment		70	90% growth of plants	Good
Check no treatment		70	95% growth of plants	Good
Check no treatment		80	100% growth of plants	Good
Check no treatment		80	100% growth of plants	Good

*Equivalent to amount of lead in lead arsenate.

The data show clearly that lead acetate and lead nitrate, applied evenly at the rate of 5 tons per acre, had no detrimental effect on alfalfa, whereas lead arsenate applied at the rate of 2 tons per acre resulted in complete crop failure. Similar results were obtained (7, 10) with lead compounds applied to the soil for barley. These experiments indicate that the arsenic, and not the lead, in lead arsenate is toxic to plants.

FLUORINE

Certain fluorine compounds, especially cryolite, have been used extensively as sprays for codling moth control. To determine the effect of these spray materials on the growth of alfalfa, samples of soil were taken from an area which had never received sprays, and which was located near an or-

[2] This is computed upon the basis of 3 pounds of lead arsenate per 100 gallons of spray, and an application of 50 gallons of spray per tree with fifty trees per acre.

chard (11). These samples received the equivalent of 1, 2, 3, 4, and 5 tons of cryolite per acre respectively, and were then seeded with alfalfa. Excellent alfalfa growth was obtained on all the treated soils. It seems that the poor growth of cover crops observed in the apple orchards is not attributable to the fluorine spray compounds of low solubility, such as cryolite.

ARSENIC

Since it appeared that the presence of arsenic in the soil was primarily responsible for the poor growth of alfalfa cover crops in apple orchards, soil samples of the surface 6 inches were obtained from a number of representative commercial apple orchards in central and southeastern Washington. The condition of the cover crop in each orchard was recorded at the time of sampling. Also, the water soluble arsenic and pH values of each soil sample were determined (Table 2).

TABLE 2.—WATER SOLUBLE ARSENIC AND pH VALUES OF SOIL SAMPLES FROM REPRESENTATIVE APPLE ORCHARDS IN CENTRAL, NORTH CENTRAL, AND SOUTHEASTERN WASHINGTON, WITH KIND AND AMOUNT OF COVER CROP GROWING.

Water soluble arsenic, p.p.m.*	Soil pH value	Location from which soil sample obtained	Condition of cover crop growth in orchard
38	5.24	Yakima	No cover crop
20	7.7	Pateros	Very sparse cover crop
36	7.34	Zillah	No cover crop
12	7.34	Oroville	Cover crop of weeds
10.5	6.9	Tonasket	Very little cover crop
28	7.32	Methow	Very poor cover crop
42	7.3	Crescent Bar	No cover crop
26	7.46	Dayton	Almost no cover crop
17	6.98	Dayton	No cover crop
10	6.7	Wenatchee	Scattered old alfalfa plants
42	4.7	Wenatchee	No cover crop
30	6.78	Wenatchee	Good rye cover crop
12	5.93	Wenatchee	Out from trees, good rye cover
12	6.42	Wenatchee	Good grass cover crop
17	5.92	Wenatchee	Good rye cover crop
13	6.18	Wenatchee	No cover crop
17	6.88	Wenatchee	Good rye cover crop

* Analysis of water soluble arsenic and soil pH values determined by Dr. L. T. Kardos, Soils Section, Division of Agronomy, Washington Agricultural Experiment Stations.

The soluble arsenic content in the surface soil of the various orchards ranged from 10 to 42 p.p.m. (parts per million). The cover crop was lacking or poor, except where weeds, rye, or grass constituted major plant growth.

Experimental plots were prepared to measure the effect of drippings from the leaves and branches of apple trees receiving an average of seven cover sprays per season for 6 years. The results indicated that in the surface 6 inches of soil the water soluble arsenic content had increased from 6.9 to 23.0 p.p.m., and the total arsenic content from 194 to 396 p.p.m., during this period. Alfalfa seeded in these plots failed to make satisfactory growth.

The Arsenic Concentration in the Soil Affects the Kind of Injury to Plant Growth—Less So, the Degree

The appearance of alfalfa seedlings grown on toxic soil in the experimental plots in the orchard at the Tree Fruit Experiment Station indicated that the injurious effect of arsenic is most noticeable in young plants. The symptoms ranged from slight discoloration of the leaves, stems, and roots, to a severe browning of the roots and collapse of the stem at the surface of the ground. Variations in temperature also affect the toxicity of arsenic on plants. Considerable variation in the degree of injury was observed from day to day, according to temperature and other meteorological factors. The alfalfa plants in all the plots made better growth as the weather became cooler later in the growing season.

Although soils low in total arsenic or water soluble arsenic content were observed to permit better growth of alfalfa than soils containing large amounts of these substances, no close relationship was found between the total amount of arsenic or the concentration of water soluble arsenic in the surface 6 inches of soil and the growth of alfalfa cover crops.

Soil properties, including texture and chemical composition, appear to have an influence on the degree of toxicity. Similar observations pertaining to symptoms of arsenic injury in various crops, and to concentration of arsenic in the soil, were reported by several investigators (1, 10, 14, 15).

According to Lindner (8), the injury thought to be caused by arsenic developed a different pattern on the foliage of young peach, apricot, and other fruit trees planted in old apple orchard land. Brown to brownish-red spots appeared first along the margins and between the veins of the older leaves. The injured areas usually died and fell out, leaving "shot holes" and a notched emargenation. Severe injury was marked by various amounts of defoliation, and often nearly complete loss of leaves, by the end of August. The trees were stunted and lacked vigor.

Arsenic Toxicity Is Concentrated Mainly in the Upper 4 Inches of Soil

Soil samples were taken at depths of 0 to 4, 4 to 8, and 8 to 12 inches in an old apple orchard. The samples taken at each depth were mixed, potted, and planted to alfalfa in the greenhouse. The soil from the surface 4 inches produced very weak alfalfa plants which died in most cases before they reached a height of 4 inches.

The soil taken from a depth of 4 to 8 inches produced a medium to good stand of alfalfa that was weak and made slow growth, but showed little discoloration of the roots and had leaves that appeared to be normal in color. The soil taken at a depth of 8 to 12 inches produced a good stand of weak, slow-growing alfalfa. The plants appeared to be normal but showed indications of lack of available plant nutrients.

During the same year, field plots in an arsenic-toxic orchard were prepared as follows: (*a*) The surface 3 inches of soil were removed and replaced with 3 inches of soil from a nearby virgin area. (*b*) The surface 3 inches of soil were removed and replaced with 3 inches of soil from a cherry orchard which had received no lead arsenate sprays. (*c*) The surface 3 inches were removed and a seed bed prepared. Alfalfa was seeded in these plots.

A full stand of alfalfa was obtained in plots (*a*) and (*b*) the first year.

The alfalfa maintained an excellent growth throughout the 6 years of the experiment. The seed germinated in plot (*c*), but the growth was weak and the color of the leaves yellowish. An application of ammonium sulfate at the rate of 500 pounds per acre during the fourth year resulted in satisfactory growth, indicating that possibly the level of soil fertility of the subsoil was low.

Although it is realized that the hauling in of virgin soil in an effort to establish an alfalfa cover crop in commercial apple orchards is not an economical procedure, the results show that when the surface 3 inches of toxic soil are replaced with nontoxic soil, the alfalfa crop was readily established and maintained, even though the arsenic content became relatively high through subsequent spraying.

Jones and Hatch (6) report that the reason mature trees in commercial apple orchards are not affected by spray residue accumulations is that these compounds are restricted to the soil mass stirred by cultivation tools. The root systems of the trees largely distribute themselves below this depth and are not in contact with the spray ingredients.

Legumes Have a Low Arsenic Tolerance

Various investigators (3, 10, 14) have shown that different crops vary markedly in tolerance to arsenic toxicity. In 1936, an apple orchard which had been sprayed heavily with lead arsenate for 20 years was selected for plot experiments with different kinds of legumes. The soil was Cashmere gravelly coarse sandy loam.

Sixteen representative soil samples taken from the surface 6 inches in this orchard had a total arsenic content ranging from 366 to 723 p.p.m. and concentrations of water soluble arsenic ranging from 13.2 to 35.5 p.p.m. The plots received no special treatments to improve tilth or reduce arsenic toxicity. Different kinds of legumes were planted during the period 1936 to 1943. All seeds used tested more than 80 per cent germination.

Plots were irrigated by sprinkling, since this method has been proved most satisfactory (22) in providing uniform soil moisture conditions for seed germination and establishment of a cover crop. An adequate supply of soil moisture at all times during the period of germination of small seeds and the early growth of seedlings is important in irrigated areas.

The experimental plots were not cultivated, except in preparation for seeding or for reseeding, where this was necessary. The legumes used and the results obtained are recorded in Table 3. None of the legumes made satisfactory growth.

In a second experiment, twenty plots were laid out in an old apple orchard with trees spaced at fifty-four per acre. The total arsenic content of the surface 6 inches of soil in various places ranged from 477 to 608 p.p.m.; water soluble arsenic, from 11.5 to 21.3 p.p.m. The experiments were continued for 6 years of seeding and reseeding with Ladak alfalfa. Weeds and grasses were controlled by hand weeding. Irrigation water was applied by sprinkling. The lead arsenate spray program in the orchard was continued during the experimental period.

At the end of 6 years, there was no stand of alfalfa in nine of the plots. Six plots produced an alfalfa stand of 10 to 40 per cent the first year. Their stand and growth improved each succeeding year. The water soluble arsenic content in these plots ranged from 11.5 p.p.m. to 21.3 p.p.m. The highest total amount of arsenic was 477 p.p.m.

An alfalfa stand of 10 to 20 per cent was produced in the other five plots the first year, but no improvement

TABLE 3.—RESULTS OF SEEDING AND GROWTH OF DIFFERENT KINDS OF LEGUMES IN MATURE APPLE ORCHARD SPRAYED HEAVILY WITH LEAD ARSENATE FOR 20 YEARS.

Kind of legume	Stand and growth
Alfalfa, Ladak (*Medicago sativa* L.)	Poor
Alfalfa, Cossack (*Medicago sativa* L.)	Poor to failure
Alfalfa, Hardistan (*Medicago sativa* L.)	Poor
Alfalfa, Common (*Medicago sativa* L.)	Poor to failure
Alfalfa, Orestan (*Medicago sativa* L.)	Poor to very poor
Medic alfalfa (*Medicago falcata* L.)	Failure
Burr clover (*Medicago Media* Pers.)	Very poor
Alsike clover (*Trifolium hybridum* L.)	Very poor
Strawberry clover (*T. fragiferium* L.)	Poor
White Dutch clover (*T. repens* L.)	Poor
Ladino clover (*T. repens* L. *var. latum*)	Poor
Alpha sweetclover (*Melilotus alba* Desr.)	Poor
White blossom sweetclover (*Melilotus alba* Desr.)	Poor
Yellow blossom sweetclover (*M. officinalis* Lam.)	Poor
Perennial lespedeza (*Lespedeza sericea* Thumb) (Benth.)	Failure
Kobe lespedeza (*Lespedeza striata* Hook & Arm)	Failure
Alaska field pea (*Pisum sativum L. var.* arvense Poir.)	Failure
Austrian winter pea (*Pisum avense* L.)	Failure
Beach pea (*Lathyrus maritimus* Bigel)	Poor
Lima bean (*Phaseolus lanatus* L. var. macrocarpus, (Benth.)	Failure
Spring vetch (*Vicia villosa* Roth)	Poor
Winter vetch (*Vicia villosa* L.)	Very poor
Perennial vetch (*Vicia tenuifolia* Roth)	Failure
Milk vetch (*Astragalus Cicer* L.)	Poor
Milk vetch (*Astragelus rubyi*)	Poor
Milk vetch (*Astragelus Muttoni*)	Poor
Fenugreek (*Trigonella foenum-graecum* L.)	Failure
Rattlebox (*Crotalaria intermedia* Kotschy)	Failure
Sainfoin (*Onobrychis viciaefolia* Scop.)	Failure

was observed in succeeding years. The water soluble arsenic content in the soil of these plots was 19.4 p.p.m. The total amount of arsenic was 608 p.p.m.

It should be noted that the arsenic content in the soil of apple orchards varies greatly in different places.

Some Soil and Fertilizer Treatments Help Alfalfa On Toxic Orchard Soils

SOIL TREATMENT

Experimental plots were laid out in 1935 in an arsenic-toxic apple orchard soil. The treatments made were as follows: One plot was flooded with water kept at a depth of several inches for 48 hours. The 4- to 8-inch layer of soil was inverted with the surface 4-inch layer in a second plot. Soil in several other plots was cultivated to a depth of 12 inches, with thorough mixing to dilute the concentration of arsenic. The alfalfa seeded on these plots produced a poor stand which failed to make satisfactory growth, except in one case where the arsenic content was relatively low.

INEFFECTIVE FERTILIZER TREATMENTS

Various kinds and amounts of fertilizers were applied to the soil of a series of plots in an arsenic-toxic orchard, and alfalfa was seeded in the plots. The weeds and grasses were controlled by hand weeding in all cases. Cyanamide applied at the rate of 800 pounds per acre, ammonium sulfate at the rate of 750 pounds per acre, and calcium nitrate at the rate of 1,000 pounds per acre, on different plots, produced no beneficial effects on the growth of alfalfa.

Muriate of potash and potassium sulfate applied at rates of 300 to 2,500 pounds per acre, and potassium hydroxide applied at the rate of 1,000 pounds per acre, produced no beneficial effect on alfalfa.

EFFECTIVE FERTILIZER TREATMENTS

Sixteen per cent superphosphate, applied at rates of 250 to 750 pounds per acre, produced beneficial effects on the growth of alfalfa. Additional applications at the rate of 500 to 750 pounds per acre, making the totals 750 and 1,500 pounds per acre for these two plots respectively, resulted in a full stand of alfalfa. In another plot, an application of 1,500 pounds of superphosphate per acre appeared to be inadequate, but a second application of a like amount the following year resulted in a full stand of alfalfa.

Applications of treble phosphate (45 per cent P_2O_5) to the soil, at the rate of 1,000 pounds or more per acre, produced satisfactory results. Amounts less than 1,000 pounds per acre weren't as effective. Colloidal phosphate applied 750 to 6,000 pounds per acre failed to produce satisfactory stands of alfalfa. The results produced with superphosphates confirm those obtained by Hurd-Karrer (5), who found that phosphate applications to the soil reduce or prevent arsenic toxicity if the soil retains the phosphate in available form.

Applications of Some Inorganic Substances Aid Alfalfa Growth On Toxic Orchard Soils

Several investigators have reported that applications of certain inorganic compounds reduce arsenic toxicity in soils. A number of compounds were applied to arsenic-toxic soils in plots in an old apple orchard to determine their value in correcting arsenic-toxic conditions.

EFFECTIVE

Aluminum sulfate applied at the rate of 1.5 tons, plus 3 tons of lime per acre to adjust the pH value of the soil, resulted in a good stand and growth of alfalfa.

Applications of 3 tons of ferrous sulfate alone per acre were not sufficiently effective in correcting the arsenic toxicity to produce a stand of alfalfa. The use of 1,000 pounds of ferrous sulfate plus 2,000 pounds of lime per acre, however, resulted in an excellent stand of alfalfa after 3 years of reseeding following the treatment.

Zinc sulfate or zinc oxide applied alone were less effective than ferrous sulfate. But when lime was added, together with the zinc compounds, a good stand of alfalfa resulted. An application of 2,500 pounds per acre of either of the zinc compounds, with 5,000 pounds of lime, also was effective in establishing a good stand.

INEFFECTIVE

Calcium sulfate (gypsum or land plaster) applied at rates of 1,200, 4,000, and 5,000 pounds per acre had no beneficial effect on establishing alfalfa, even after three annual reseedings following the treatment.

Lime applied at the rate of 10 tons per acre, in two tests, was of no appreciable value.

Sulfur applied alone at the rate of 1 ton per acre, and at 2 tons per acre with 2 tons of lime, did not result in a satisfactory stand. Finely ground lime-sulfur sludge and lime-sulfur spray solution were tried without effect.

Manure Is One of the Better Organic Substances for Alfalfa on Toxic Orchard Soils

Mally (9) and Vincent (16) found that applications of manure to arsenic-toxic soils reduced the degree of toxicity. Manure, alfalfa hay, straw, and peat were applied to the soil as mulches, singly and together with certain other materials, to determine their effect on arsenic toxicity.

EFFECTIVE

The addition of dry cow manure to arsenic-toxic soil at rates of 2.5 to 5 tons per acre was helpful in establishing alfalfa. Additional application of 7 tons of dry manure per acre resulted in increased benefit. In every case where unrotted, dry farm manure containing some straw was applied at the rate of 7 tons per acre, and weed growth was controlled, a good stand and growth of alfalfa resulted the first or second year following treatment.

Poultry litter applied annually at the rate of 2 tons per acre resulted in a full stand of alfalfa in 2 to 4 years.

INEFFECTIVE

When wheat straw was applied at the rate of 1 to 4 tons per acre, a satisfactory stand of alfalfa was obtained after two or three reseedings. But when the straw was supplemented with 1,500 pounds of zinc sulfate, satisfactory growth of alfalfa occurred within 2 years. The experimental results show that applications of as little as 5,000 pounds of straw per acre, supplemented with ammonium sulfate or sodium nitrate, are beneficial in establishing alfalfa as a cover crop. When repeated annually for several years, a good alfalfa cover crop may be established. This practice constitutes a desirable, economical orchard soil management program.

Peat applied alone as a mulch at the rate of 2 to 4 tons per acre annually for 3 years, or a single application of 10 tons per acre, resulted in satisfactory stands of alfalfa. Supplementing the peat, when applied at the rate of 2 to 3 tons per acre, with 200 to 400 pounds of ammonium sulfate to supply the needed nitrogen for the trees, and with 100 to 200 pounds of ferrous sulfate, proved to be helpful in further counteracting the toxic effect of arsenic for alfalfa.

Alfalfa hay applied at the rate of 2 tons per acre did not result in a satisfactory stand of alfalfa.

Some Legumes Are Better Than Alfalfa for Arsenic-toxic Soils

The experimental results obtained with a number of legumes that are suitable for orchard cover crops show that the following are more tolerant to arsenic toxicity than is alfalfa: white blossom, yellow blossom, and Hubam sweetclovers; strawberry clover, Ladino clover, and White Dutch clover.

The sweetclovers may maintain a partial stand for several years by self-reseeding, but new seedings are required every 2 years to maintain a full stand.

Strawberry clover appeared to be as tolerant to arsenical residues as any of the legumes on both heavy and light soils, when the water supply is abundant at all times.

Ladino clover grows well under irri-

gation. It is a promising cover crop for arsenic-toxic orchard soils, especially those that are irrigated by sprinkling. It produces seed abundantly and reseeds itself readily. Ladino clover makes a heavy top growth which should be cut in the fall to prevent smothering and dying of the crop during winter in areas with heavy snow fall. Cutting also lessens the problem of mice infestation.

White Dutch clover prefers moist, cool situations. Like alfalfa, it starts slowly. As growth continues, the plants spread by means of aboveground horizontal stems which root in arsenic-toxic soil.

Alsike clover, perennial and Kobe lespedeza, peas, vetches, fenugreek, Crotalaria and sainfoin were included in the experimental work. Alsike clover did not prove to be very satisfactory, since most stands were poor. The lespedezas and peas grew poorly, or not at all, in arsenic-toxic soils. The hairy vetch was the most tolerant to arsenic toxicity among the vetches, and is the only one which showed any promise at all. The fenugreek, Crotalaria, and sainfoin proved to be failures.

Of the Non-Legumes, Most Grasses Are Better Than Cereals for Cover Crops in Arsenic-toxic Soils. Rye Is the Best Cereal

Certain cereal crops and grasses have been used extensively as orchard cover crops in some fruit growing areas in this country. Some cereal crops are much more tolerant than others to arsenic toxicity (9, 17). Observations in apple orchards in central Washington show that certain grasses

TABLE 4.—RESULTS OF SEEDING DIFFERENT KINDS OF CEREAL CROPS IN ARSENIC-TOXIC SOIL IN A MATURE APPLE ORCHARD.

Kind of plant	Stand and growth
Horseford barley	Poor
White winter barley	Medium
Wisconsin barley	Poor
Woodward winter barley	Poor
Abundance oats	Poor
Cox oats	Poor
Karnota oats	Poor
Markton select oats	Poor
Obtusata side oats	Medium to poor
Silvermine oats	Failure
German rye	Good
Rosen rye	Excellent
Abruzzi rye	Excellent
White winter rye	Good
Rye wheat hybrid	Good
Baart spring wheat	Poor
Hymar winter wheat	Poor
Jones fife wheat	Poor
Little club wheat	Poor
Marquis wheat	Poor
Red Russian winter wheat	Medium
Beardless wild rye, perennial	Good
Redit wheat	Poor

appear to be relatively tolerant to arsenic toxicity.

It was of interest, therefore, to determine the relative tolerance of a number of cereal crops and grasses to the toxic effect of arsenic in the soil of old apple orchards. Two series of plots were prepared in a mature orchard at the Tree Fruit Experiment Station. One series of plots was seeded to a large number of cereal crops, the other to a number of common grasses. The cereal crops used and the results obtained are given in Table 4.

CEREALS

All the varieties of rye proved to be more tolerant to the arsenic conditions than any of the other cereal crops. They produced an excellent stand and growth.

The varieties of oats and wheat used showed no promise as orchard cover crops in arsenic-toxic soils.

Among the varieties of rye, Abruzzi rye produced the heaviest top growth, but it appeared to be less winter hardy than Rosen rye. Both of these varieties, however, are well adapted to orchard conditions in central Washington, and could be used effectively as an orchard cover crop substitute for alfalfa or other legumes where arsenic toxicity is a problem. Rye is one of the best cover crops for soils that are low in fertility and organic matter. With an ample supply of available nitrogen provided by nitrogen fertilizers, rye makes good growth early and late in the season when temperatures are low. It is easily established and can be seeded at almost any time during the year.
and the results obtained are given in Table 5.

GRASSES

The grasses used in the experiment and the results obtained are given in Table 5.

TABLE 5.—RESULTS OF SEEDING DIFFERENT KINDS OF COMMON GRASSES IN ARSENIC-TOXIC SOIL IN A MATURE APPLE ORCHARD.

Seed planted	Stand and growth
Big bluegrass perennial	Good to medium
Canada wild rye perennial	Medium
Crested wheat grass perennial	Medium to poor
Italian rye grass short-lived perennial	Good
Kentucky bluegrass	Good
Meadow fescue perennial	Good
Orchard grass perennial	Good
Quackgrass perennial	Good
Redtop	Good to medium
Reed canary grass perennial	Failure
Smooth brome perennial	Poor to very poor
Sudan grass perennial	Medium
Timothy perennial	Medium

All the grasses used, except reed canary grass, proved to be as good as or better than the cereal crops in their tolerance to arsenic toxicity. Italian rye grass, Kentucky bluegrass, meadow fescue, orchard grass, and redtop showed the best promise as grass orchard cover crops in arsenic-toxic soils. The underground horizontal stems by which these grasses spread were but slightly affected by the arsenic in the soil. The roots that reached a depth of 5 inches were generally normal in appearance and growth.

Quack grass has an advantage over other grasses in that in addition to the top growth it also contributes much organic matter through the profuse growth of the underground rhizomes. A disadvantage is that it requires an abundance of water and nitrogen fertilizers for good growth.

OTHERS

Several miscellaneous non-legume crops, other than grasses, were included in the experiments. They are: bison flax, cowhorn turnip, dwarf Essex rape, and southern giant-curled mustard. All failed in stand and growth.

Summary

1. Continuous spraying of apple orchards with lead arsenate has resulted in the surface soil of apple orchards becoming toxic to many kinds of cover crops, especially legumes.

2. It is the arsenic in lead arsenate that is toxic to orchard cover crops, not the lead. The relatively insoluble fluorine compounds used in codling moth control aren't a problem in soil toxicity.

3. Applications of phosphate fertilizers were only partially effective in counteracting arsenic-toxic conditions of orchard soils. Large quantities, amounting to 1,000 to 1,500 pounds of 16 per cent superphosphate per acre, were effective in establishing a stand and growth of alfalfa in 1 year's time. Other fertilizers or soil amendments used showed only partial or no benefit in establishing legume cover crops.

4. Relatively heavy applications of aluminum sulfate, ferrous sulfate, and zinc sulfate were partially effective in establishing alfalfa as a cover crop in toxic soils. Heavy applications of calcium sulfate gave no beneficial effect.

5. The use of lime and various sulfur compounds alone, or in combination with other materials, was not effective in counteracting the arsenic-toxic condition of apple orchard soils for leguminous crops.

6. When 1 ton per acre of wheat straw was applied, a satisfactory growth and stand of alfalfa was obtained after three to four successive annual seedings. Using 3 tons of straw per acre, supplemented with 500 pounds of sodium nitrate, a full stand and good growth of alfalfa was obtained from the first seeding.

7. The application of 5 to 7 tons per acre of dry manure was effective in the establishment of alfalfa.

8. The data indicate that the response of cover crops was not proportional to the concentration of arsenic in the surface 6 inches of the soil. However, soils relatively low in arsenic generally permitted a better crop growth than soils high in arsenic.

9. The common grasses in general proved to be more tolerant of arsenic toxicity in the soil than legumes or cereals, except possibly rye. On the basis of tolerance, Italian rye grass, Kentucky bluegrass, fescues, redtop, orchard grass, and quack grass showed the greatest promise for permanent grass cover crops.

10. Rosen rye, Abruzzi rye, white winter rye, rye-wheat hybrid, and Red Russian wheat were the most arsenic-tolerant cereal crops. Rosen rye and Abruzzi rye can be used effectively as a substitute for legumes.

11. The legumes are less tolerant than grass crops. Sweetclover, strawberry clover, Ladino clover, and White Dutch clover are more tolerant than alfalfa.

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